Design of Single Layered Circular and Rectangular U-Slotted, CPW-Fed Antennas and Arrays for RFID Applications

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***Abstract*—This work describes the design of high gain, U-slot antennas for RFID 915 MHz (902 – 928 MHz) applications. Four types of antenna were designed, optimized and evaluated – a circular, U-slotted antenna, a rectangular U-slotted antenna, and two 2x1 arrays. All structures are fed using the co-planar waveguide (CPW) feed. Several miniaturization and gain enhancement techniques such as folding, bending and alternative feeding were applied in the course of achieving the required compactness and radiation characteristics. After investigation, a rectangular, single element U-slot antenna was proposed as the most suitable for this application, considering that it provides a reasonable gain, sufficient bandwidth and compactness.**

Keywords-radio frequency identification (RFID), microstrip antenna, slot antenna, antenna array, co-planar waveguide (CPW) feed

I. INTRODUCTION

In recent years the growth of the wireless and Radio Frequency Identification (RFID) industry has prompted researchers to extend their component design and research effort, especially within the 915 MHz frequency range (902 – 928 MHz). This band has been proven to be useful, especially with its excellent immunity to environmental noise and electrical interference, minimal shielding effects from adjacent objects and the human body, freedom from environmental reflections that can plague UHF systems, good data transfer rate and cheap ICs, disposable tags and cost effective antenna coil manufacturing [1].

There are several types of the antenna architectures that have been implemented in the RFID industry, such as single dipoles [1], M-tags, I-tags, X-tags, squiggle tags [2] and etc. In this work, two types of U-slot shaped antennas will be discussed, implemented on a microstrip structure, and measured. One is designed to be of circular U-shape, while the other shows a rectangular U-shape. The U shape has been chosen as a fundamental way in order to provide a small starting dimension prior to optimization. Although meander-lined structures and other folded structures have been more popularly implemented by previous researchers [3-6], it was observed that the conventional slotting of a microstrip structure provides a structure which is similar to meanderlines and folded dipoles/monopoles [7-10]. This ensures a better gain and efficiency, with a reasonable amount of bandwidth and maintained simplicity, without the need for a matching circuit.

II. ANTENNA DESIGN METHODOLOGY

Both antennas were designed using the same substrate and simulator in order to provide a generic platform for benchmarking. The FR-4 substrate (ε_r = 4.7 and tanδ = 0.019) with a thickness (h) of 1.6 mm, was chosen as it provides the most cost effective material in antenna prototyping. Agilent's Advanced Design System (ADS) was used as the simulator.

A. *Single Circular U-Slot Antenna (CUSA) Design*

The single CUSA was designed to resonate between 902 MHz and 926 MHz. Figure 1 shows the structure and dimensions of a microstrip dipole of length, L, and width, W, that was used in the simulation. The antenna was found to be responsive to dimensional alterations, especially concerning parameters such as the width, W and length L, length and shape of the U-slot, gap height and its position.The antenna was designed to have a footprint of about 37 x 63 mm, and its maximum radial size was about 17.6 mm. Optimization has been done by varying the calculated parameters in order to optimize the S_{11} parameter. The dimensions of the design are shown in Table I.The CPW feed was sized at about 1 mm, and the slots were sized at about 1.6 mm.

B. *Single Rectangular U-Slot Antenna (RUSA) Design*

A single RUSA was designed similarly as a single CUSA. However, the footprint produced for the antenna was only about 27 x 52 mm.

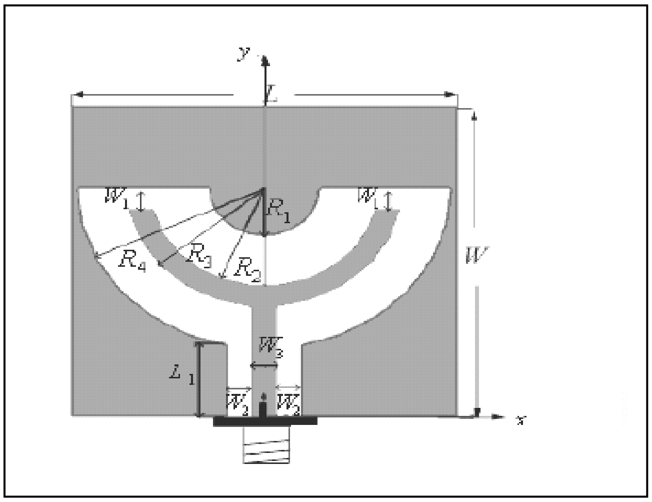

Figure 1. Dimension definition of the Circular U-Slot Antenna (CUSA)

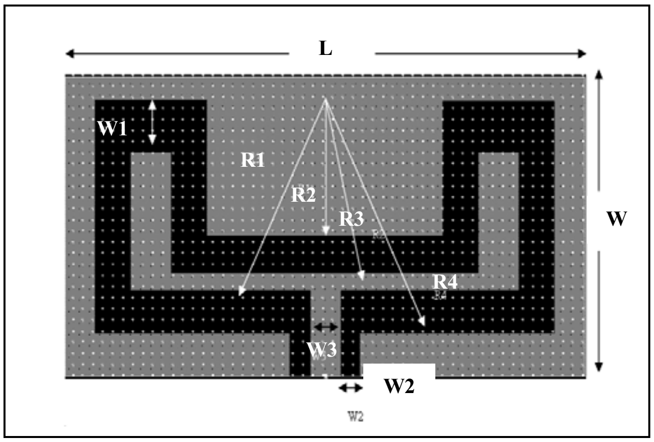

Figure 2. Dimension definition of the Rectangular U-Slot Antenna (RUSA)

However, each element radial size was larger by about 3.5 mm compared to the circular shaped CUSA. The slot edge transitions are more abrupt, and produced a different slot pattern, especially at the edges, where the slot size (W1) were increased about three times in order to produce the same resonance at 915 MHz. This design is shown in Figure 2. The same material specification was used in this design, and the important parameters were again found to be the width (*W*) and length (*L*). The dimension of the design is shown in Table I.

C. *Double Circular U-Slot Antenna (DCUSA) Design*

An array configuration can further improve the radiation pattern and significantly decrease the cross polarization level in the higher frequency range and consequently increase the usable bandwidth for RFID applications. To prove this, a two element array is constructed as shown in Figures 3 and 4. Comparisons of return loss between single slot and double slot structures are shown in Figures 6 and 7.

TABLE I. DIMENSION OF THE DESIGNED SINGLE AND DOUBLE U-SLOT ANTENNAS

Antenna Type/ Parameters and values (in mm)	***Single Circular U-Slot Antenna (CUSA)***	***Single Rectangular U-Slot Antenna (RUSA)***	***Double Circular U-Slot Antenna (DCUSA)***	***Double Rectangular U-Slot Antenna(DRUSA)***
L	37.0	26.9	52.0	51.4
W	62.9	52.0	52.7	28.3
R1	10.1	12.1	4.7	7.0
R2	12.9	15.5	6.7	7.4
R3	14.9	17	9.7	8.6
R4	17.6	20.9	10.9	9.3
R5	NA	NA	15.7	15.0
R6	NA	NA	17.1	16.0
R7	NA	NA	19.3	17.4
R8	NA	NA	20.0	19.2
W1	1.6	4.6	1.4	1.2
W2	1.0	2.1	NA	NA
W3	0.9	3.0	NA	NA
W3, W5, W7	NA	NA	1.4	1.4
W2, W4. W6	NA	NA	2.5	2.2

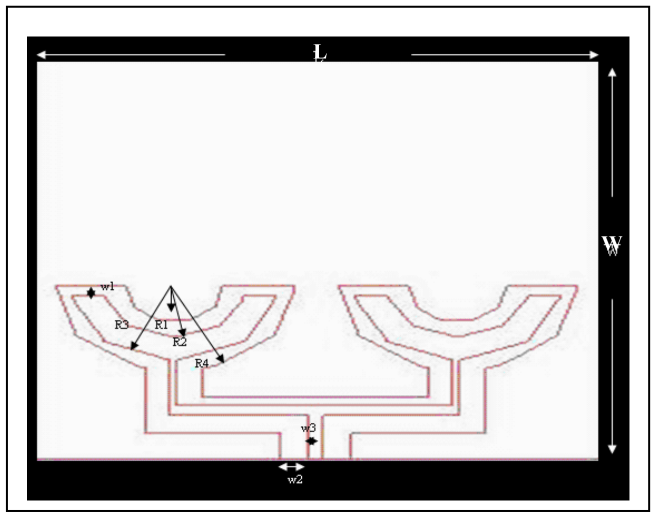

Figure 3. Dimension definition of the Double Circular U-Slot Antenna (DCUSA)

A 2x1 array of circular U-slot antenna was designed using two paired U-slot antennas fed by a corporate CPW feeding line The geometry of the proposed coplanar waveguide (CPW) antenna is shown in Figure 3 and Table I. The length of the antenna was designed to be longer with 52 mm compared to 37 mm for single CUSA, but smaller in terms of width, 52.7 mm for a DCUSA and 62.9 for a single CUSA. Due to the small footprint available, the maximum radial length for a DCUSA (R4) was designed to be about half the size of its singular (R4), in order to place two elements on a miniaturized footprint.

Contrary to the single CUSA which used a smaller CPW feed size, W2 and W3 for DCUSA was sized at 2.5 mm and 1.4 mm, respectively.

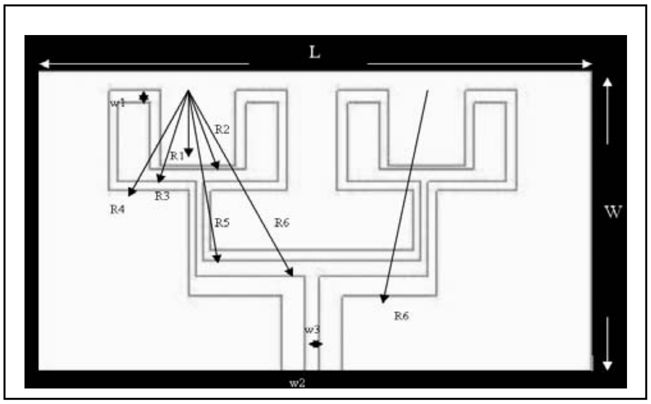

Figure 4. Dimension definition of the Double Rectangular U-Slot Antenna (RCUSA)

The dimensions of the double CUSA, in comparison to all other antenna structures are shown in Table I. The optimized width and radius of this antenna are found to be smaller than for the miniaturized single CUSA structure.

D. Double Rectangular U-Slot Antenna (DRUSA) Design

The geometry of the second type of 2x1 array with rectangular element (DRUSA) is shown in Figure 4. This antenna was also designed with only one layer of FR4 substrate. The dimensions of this design are also smaller than for the previous single RUSA structure.

The fabricated antenna was sized at 28.3 x 51.4 mm, with its width about hald the size of a single element RUSA. Its largest radial length for a single element was also halved in order to place the two separate elements. Detailed dimensions of this structure are shown in Table I. The CPW feedline was similarly designed as of the DCUSA's, with a width (*W3*) of 1.4 mm and gap distance (*W2*) of 2.2 mm.

III. RESULTS AND DISCUSSION

The results for the single U-slot and rectangular U-slot patch antenna will be discussed first. The simulation results for the reflection coefficient are shown in Figure 5.

The bandwidth produced by the CUSA operating at 915 MHz is twice larger than the one for the RUSA - CUSA produces a bandwidth of 16.2 MHz while RUSA produces a bandwidth of only 7.8 MHz. It is also found that the RUSA produces a higher gain (3.21 dBi) although being smaller in size. The CUSA design was sensitive to several parameters such as the gap of the feedline, *W2*, patch length, *L*, width, *W* and the slot width, *W3*. Moreover, the RUSA structure was more easily drawn and optimized.

From the simulated radiation pattern, the gain, directivity and efficiency have been obtained. They are shown in Table III. The maximum difference between co-polarization and cross polarization (isolation) for CUSA was 55 dB, and 120 dB for RUSA. The reflection coefficient comparison between the double elements (DCUSA versus DRUSA) is shown in Figure 6.

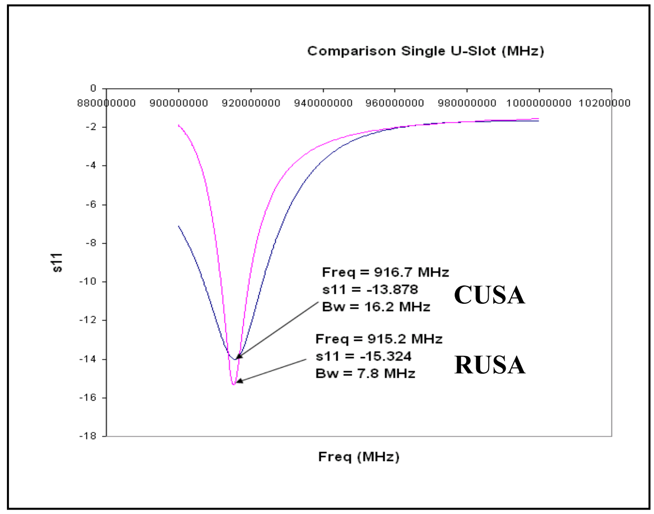

Figure 5. Reflection performance comparison between CUSA and RUSA

TABLE II. SIMULATED GAIN, DIRECTIVITY AND EFFICIENCY OF BOTH U-SLOT ANTENNAS

Parameters and values (in mm)			
	Gain (dB)	***Directivity***	***Efficiency (%)***
CUSA	2.69	2.71	99.0
RUSA	3.21	3.23	99.0
DCUSA	2.85	2.85	99.9
DRUSA	2.52	2.52	99.9

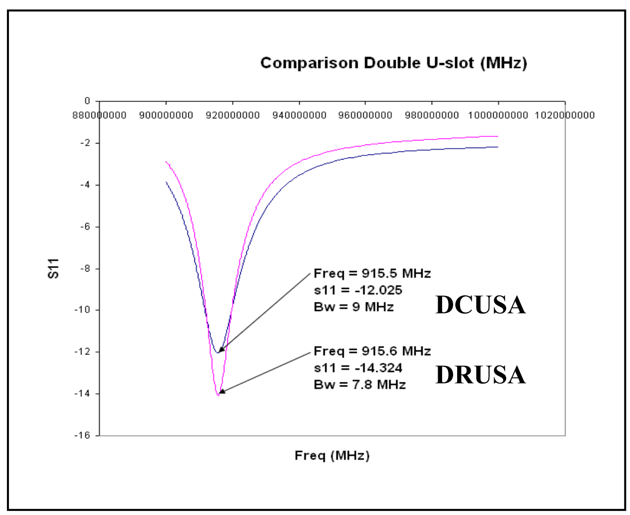

Figure 6. Reflection performance comparison between CUSA and RUSA

The simulated bandwidth of DRUSA was narrower than for DCUSA. The -10-dB bandwidth for the DCUSA design was between 911.6 and 919.7 MHz, which corresponds to 0.89 %. The minimum of S11 is -12.025 dB. The gain was found to be 2.85 dB. The -10-dB bandwidth for the DRUSA was between 911.2 and 919 MHz, corresponding to 0.85 %.

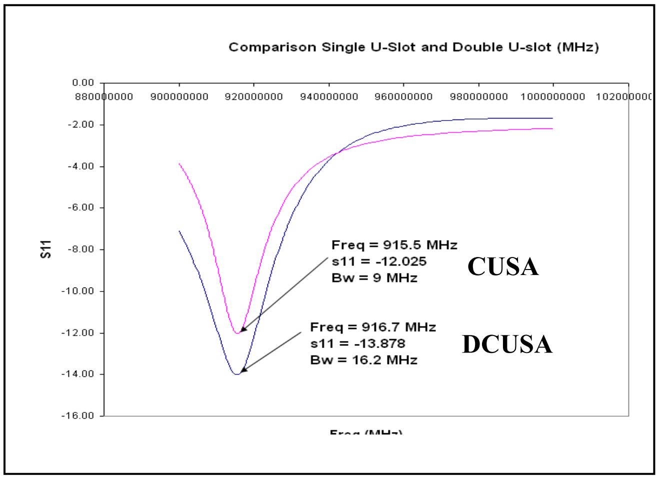

Figure 7. Reflection performance comparison between CUSA and DCUSA

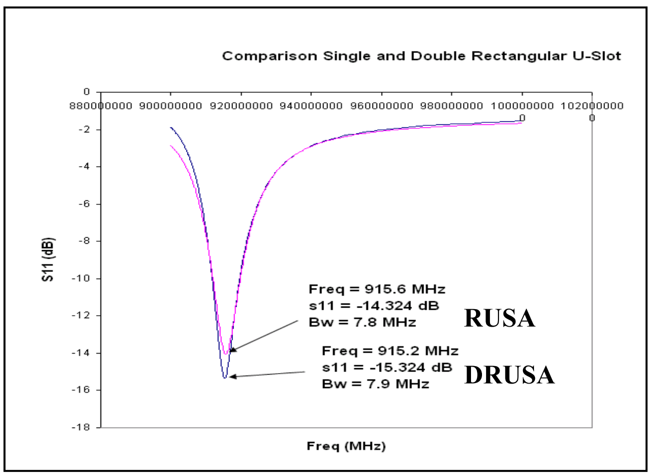

Figure 8. Reflection performance comparison between RUSA and DRUSA

The minimum S11 however was lower: -14.324 dB. The peak antenna gain was found to be slightly lower, at 2.52 dB. The radiation characteristics are summarized in Table III. It is seen that the efficiency is almost 100 %.

The comparison between single and double element slot antennas is shown in Figures 7 and 8, for circular and rectangular U-slots, respectively. The simulated return loss of the DCUSA is minimal at 915.6 MHz with 0.89 % bandwidth (911.6 – 919.7 MHz), while the simulated return loss of the single CUSA is minimal at 915.5 MHz with a greater bandwidth of 1.77 % (904.5 – 920.7 MHz). This is due to the coupling between the elements of the slotted structure. However, in line with array theory, the peak gain of the double slot is higher than the one for the single slot.

In Figure 8, a single rectangular slot (RUSA) was compared with the double rectangular slot structure (DRUSA). RUSA’s simulated bandwidth was found to be 0.86 % (911.8 to 919.7 MHz) compared to DRUSA’s 0.78 % bandwidth. DRUSA’s gain was also found to have dropped slightly.

IV. Conclusions

Four types of U-slot CPW antennas have been proposed and implemented. Two of them involved a single element design (circular and rectangular slots), while the other two are array structures. The proposed topologies are designed to operate in the 915 MHz band. The effect of pairing the single elements slightly increases the gain of each respective slot antenna. However, the best performing structure is still found to be the single element rectangular U-slot antenna, as it provides a reasonable gain, sufficient bandwidth and is also compact in size.

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